A Comparison of Lung Function Values Among a SCUBA Diver Population and in Comparison to a Non-diver Population

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The purpose of this study was to investigate possible correlations between lung function values (PEF, IRV, ERV, and FVC) among a diver population, as well as in comparison to a non-diver population. Independent variables for both populations were biological sex, age, and weekly physical activity. Independent variables for the diver population were dive tenure, number of logged dives, certification level, and gas mixture used. A spirometry test was conducted to collect lung function values of both populations. Data from this study suggest a statistically significant relationship between diver and non-diver sex and FVC, diver age and ERV, diver sex and ERV, and non-diver FVC and weekly physical activity.

Introduction

Respiration is the process of exchanging carbon dioxide (CO_2) for oxygen (O_2). During inspiration, O_2 is inhaled and travels through either the nose or mouth, down the trachea, into the bronchi[3]. The bronchi bifurcate until they become bronchioles which will then lead to alveoli in the lungs. Here, CO_2 is retrieved from erythrocytes, and O_2 is carried away. The CO_2 is then expired[3].

Spirometry is one method of studying pulmonary ventilation. While spirometry can measure a variety of values, only four of these values were analyzed in this study. Inspiratory reserve volume (IRV) is the volume of air that can be inspired above tidal volume will a forceful inspiration. Expiratory reserve volume (ERV) is the volume of air that can be expired with a forceful expiration[4]. Peak expiratory flow rate (PEFR) is the maximum rate at which an individual can exhale. Vital capacity (VC) is the sum of IRV, ERV, and V_T. V_T, or tidal volume, is the volume of air that moves in and out during a single breath[3] (Table 1).

When SCUBA diving, divers breath using compressed air. The reason is that, when at depth, pressure increases approximately 1 atm every 10m. This increased ambient pressure requires that the inspired air be at a higher pressure in order to keep the lungs inflated. Divers must take caution when diving, as both the increased ambient pressure and the increased pressure of inspired air can lead to several dangerous physiological effects. Some of these effects include decompression sickness, nitrogen narcosis, and, in cases of faulty equipment, carbon dioxide poisoning[4]. A publication by Tetzlaff and Thomas further discusses the physiological changes that occur while at depth. At depth, the gas in one's cylinder increases in density due to an increase in the ambient pressure. An increase in gas density will also increase resistance in the pulmonary tract. The increased work needed to expand the lungs at depth could lead to decreased rate of gas exchange at the alveoli[9].

Besides compressed air (79% nitrogen and 21% oxygen), divers may also become certified to use enriched air, or NITROX. NITROX has a higher oxygen content[5]. While the decreased nitrogen content decreases the chances of the diver experiencing the effects of nitrogen under pressure, new risks are associated with an increased pO_2[5]. One of these effects is known as acute oxygen poisoning. Acute oxygen poisoning commonly leads to epilepsy followed by a coma[4]. Divers who complete an enriched air course are educated on how to minimize the risk associated with diving with enriched air. A study completed by Zenske and colleagues suggest that diving with NITROX may impair function of smaller components of the respiratory tract[12].

Several studies have been conducted to study lung function in relation to diving. In a study conducted by Crosbie and his colleagues, there was a positive correlation between FVC and diving exposure up to thirty years of age[2]. Participants in this study were all males and only dove using regular air, not NITROX. The study suggested that there may be a small increase in FVC due to adaptations to SCUBA diving. The study also suggest that this increase could be caused by increased diving exposure, increased resistance in airways, swim training, and SCUBA equipment.

Another study was completed at the University of Adelaide by Dr. Anne Wilson. This study referenced an earlier study which suggested that increased diving experience can lead to changes in pulmonary function. Contrary to Crosbie's study, however, she found a decrease in FVC among participants[11&12].

The purpose of this study is to see if there is any correlation between the PEF, FVC, IRV, and ERV between SCUBA divers and non-divers. Also, several variables, such as diver certification level, dive tenure, and gas mix, will be studied to see if there is any correlation between these variables and lung function values in SCUBA divers.

Methods

There were fifty total participants in this study. Twenty-five were classified as non-diver, and twenty-five were divers. Among the twenty-five non-divers, eight were male and seventeen were female. The age range for the non-diver participants ranged from 17 years old to 58 years old. Six non-diver participants identified as African American, while nineteen identified as white/non-Hispanic. Only one non-diver participant was a smoker. Two separate non-diver participants stated that they suffered from a chronic pulmonary illness (asthma and exercise induced asthma). Four of these participants stated that participated in little to no physical activity per week; twenty stated that they participated in a moderate amount of weekly physical activity, and only one stated that they participated in an above average amount of weekly physical activity.

The other twenty-five participants were divers. In order to be classified as a diver, a participant had to hold a current SCUBA diver certification (i.e. not a PADI® Open Water student), and the participant must have dove at least once with SCUBA in the past two years. Of the twenty-five diver participants, seventeen were male and eight were female. One diver participant identified as being a race other than White/ non-Hispanic, Hispanic, or African American. The age range of the diver participants ranged from 16 years of age to 58 years of age. At the time of data collection, five diver participants held Open Water certifications, seven held Advanced Open Water Certifications, four held Rescue Diver Certifications, and nine held Professional level certifications (Divemaster or above). The number of dives logged by diver participants ranged from 7 to 7400. Dive tenure, or the number of years a diver participant has been diving, ranged from 2 years to 40 years. Nine diver participants used NITROX regularly, fifteen dove with air, and one dove with Trimix. Twelve participants stated that they participated in a moderate amount of physical activity outside of SCUBA diving per week, while thirteen participants stated that they participated in an "above average amount" of physical activity per week. No one in the diver sample stated that they participated in "little to none" physical activity per week. One diver participant stated that they were involved in a dive injury (AGE), and only one diver participant identified as a smoker. No one in the diver sample stated that they suffered from a chronic pulmonary illness.

Table 1: Summary of spirometry terminology[3&4].

Term	Abbreviation	Definition	Average
Inspiratory Reserve Volume	IRV	Volume of air that can be inspired with a forceful inspiration	3L
Expiratory Reserve Volume	ERV	Volume of air that can be expired with a forceful expiration	1.1 L
Tidal Volume	V_T	Volume of air that enters and exits the lungs during a normal inspiration	0.5L
Vital Capacity	VC	Volume of air that can be expired following a forceful inspiration; ∑ IRV, ERV, and V_T	4.5L
Peak Expiratory Flow Rate	PEFR	Maximum exhalation rate	Males: 9L/s Females: 7L/s

Participants in both samples were selected at random and asked to complete the IRB liability form, the research survey, and complete a spirometry test using Logger Pro Mini. After the spirometry test was performed, the graph produced was analyzed in order to extrapolate the PEF, IRV, and ERV. The FVC was then calculated from the IRV and ERV. After all the data were collected, the data were analyzed using linear regression. When looking at correlations between the dependent variables (PEF, IRV, ERV, and FVC) and age, dive number, and dive tenure, a scatter plot was created and a linear regression analysis was used to analyze the data. When looking at correlations between the dependent variables and sex, certification level, gas mix, and weekly physical activity, the variables were coded (i.e. male= 0 and female=1), and, using the regression analysis function of Microsoft Excel, the data from these categorical variables were analyzed.

Results

The mean PEF for divers was calculated to be 5.43 L/s. The mean IRV was calculated to be 2.09L. The mean ERV was calculated to be 2.26L. The mean diver FVC was calculated to be 4.25L. For non-divers, the mean PEF was calculated to be 3.22L/s. The non-diver mean IRV was calculated to be 1.89L, while the mean ERV was calculated to be 1.80L. The non-diver mean FVC was calculated to be 3.70L. The mean lung function values for divers and non-divers are summarized in Table 2.

Table 2. Mean lung function values for divers and non-divers

	Mean PEF	*Mean IRV*	*Mean ERV*	*Mean FVC*
Divers	5.43L/s	2.09L	2.26L	4.25L
Non-Divers	3.22L/s	1.89L	1.80L	3.70L

Diver V. Non-Diver: Sex

Comparing male and female divers, the mean male PEF was calculated to be 6.10L/s, while mean female PEF was calculated to be 4.00 L/s. Male diver IRV was calculated to be 2.09, while mean female IRV was calculated to be 2.10L. Mean ERV for both male and female divers was calculated to be 1.50L. Mean male diver FVC was calculated to be 3.79L, while mean female FVC was calculated to be 3.60L.

In regard to male and female non-divers, male non-divers mean PEF was calculated to be 3.86 L/s, and female non-diver mean PEF was calculated to be 2.92 L/s. Male non-diver mean IRV was calculated to be 2.35L, while female non-diver mean IRV was calculated to be 1.68L. Male non-diver mean ERV was calculated to be 2.42L, ,while female non-diver mean ERV was calculated to be 1.51L. Mean male non-diver FVC was calculated to be 4.77L, and mean female non-diver FVC was calculated to be 3.19L. The mean lung function values are summarized in Figure 1.

Using regression statistics, the r-squared value for non-diver PEF in relation to sex was equal to 0.0859 with a P-value of 0.1559002. The non-diver IRV in relation to sex had a r-squared value of 0.15026609 and a p-value of 0.555424, while non-diver FVC in relation to sex had an r-squared value of 0.33029971 with a p-value of <0.01.

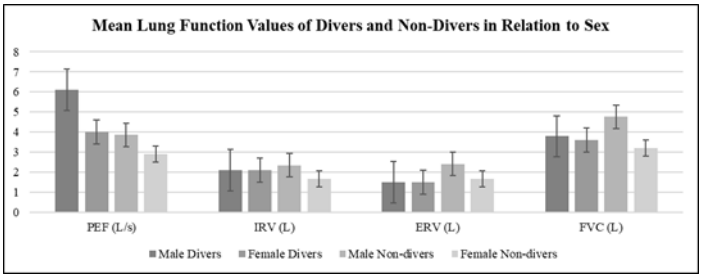

Figure 1. Mean lung function values of male and female divers and non-divers

Also using regression statistics, the r-squared value for diver PEF in relation to sex was calculated to be 0.13780051 with a p-value of 0.06. The diver IRV r-squared value in relation to sex was <0.01 with a p-value of 0.99, while the r-squared value for diver ERV in relation to sex was 0.24 with a p-value of 0.01. Diver FVC in relation to sex had a r-squared value of 0.18 with a p-value of 0.03. The r-squared values and p -values for non-divers and divers in relation to sex are summarized in Table 3.

Table 3. R-squared and p-values of lung function values of divers and non-divers in relation to sex. A "*" indicates statistical significance.

		Divers	Non-divers
PEF	*R-Squared*	0.14	0.86
	P-Value	0.06	0.15
IRV	*R-Squared*	<0.01	0.15
	P-Value	0.99	0.55
ERV	*R-Squared*	0.24*	<0.01
	P-Value	0.01*	0.8
FVC	*R-Squared*	0.18*	0.33*
	P-Value	0.03*	<0.01*

Divers V. Non-Divers: Age

All mean lung function values for this portion of the study are listed at the beginning of this section. For diver PEF in relation to age, the r-squared value was calculated to be 0.01 with a p-value of 0.53, while non-diver PEF in relation to age produced an r-squared value of <0.01 with a p-value of 0.76. The diver IRV in relation to age produced an r-squared value of 0.03 with a p-value of 0.41, while non-diver IRV in relation to age produced an r-squared value of 0.07 with a p-value of 0.18. Diver ERV in relation to age produced an r-squared value of 0.24 with a p-value of 0.01, while non-diver ERV in relation to age produced an r-squared value of <0.01 with a p-squared value of 0.8. Diver FVC in relation to age gave a r-squared value of 0.11 with a p-value of 0.11, while non-diver FVC in relation to age produced a r-squared value of

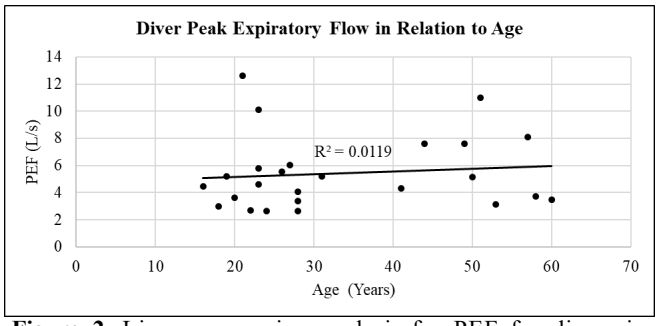

Figure 2. Linear regression analysis for PEF for divers in relation to age.

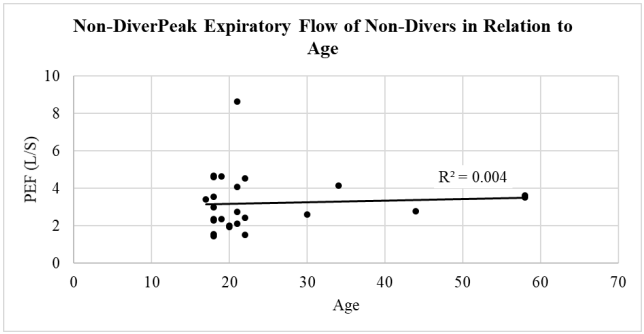

Figure 3. Linear regression analysis for non-diver PEF in relation to age.

0.02 with a p-value of 0.48. The r-squared and p-values of lung function values in relation to age are summarized in Table 4. The linear regression for PEF for divers can be viewed in Figure 4, while the linear regression for non- diver PEF can be viewed in Figure 5. The linear regression for IRV, ERV, and FVC in relation to age for divers and non-divers can be viewed in Figures 5 and 6 respectively.

Table 4. R-squared and p-values of lung function values of divers and non-divers in relation to age. A "*" indicates statistical significance.

		Divers	Non-divers
PEF	*R-Squared*	0.01	<0.01
	P-Value	0.53	0.76
IRV	*R-Squared*	0.03	0.07
	P-Value	0.41	0.18
ERV	*R-Squared*	0.24*	<0.01
	P-Value	0.02*	0.8
FVC	*R-Squared*	0.11	0.02
	P-Value	0.11	0.48

Diver V. Non-Divers: Physical Activity

The mean PEF, IRV, ERV, and FVC for divers who participated in moderate physical activity weekly were 5.473L/s, 2.040L, 2.052L, and 4.102L respectively. The mean PEF, IRV, ERV, and FVC for divers who participated in an above average amount of physical activity weekly were 5.383L/s, 2.133L, 2.264L, and 4.397L respectively. No diver claimed to have participated in little to no physical activity weekly.

Regression analysis was used to determine the relationship between PEF, IRV, ERV, FVC and weekly physical activity in divers. Diver PEF in relation to weekly physical activity produced a r-squared value of <0.01 and a p-squared value of 0.94. Diver IRV in relation to weekly

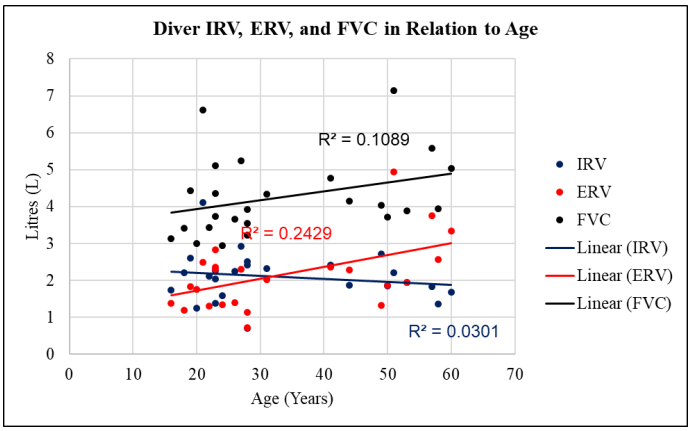

Figure 4. Diver IRV, ERV, and FVC in relation to age.

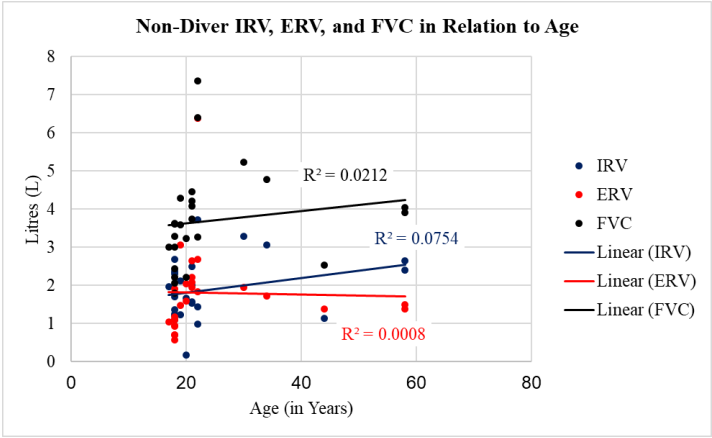

Figure 5. Linear regression analysis of non-diver IRV, ERV, and FVC in relation to age.

physical activity produced a r-squared value of <0.01 with a p-value of 0.76, while diver ERV in relation to weekly physical activity gave a r-squared value of 0.01 with a p-value of 0.58. The r-squared value of diver FVC in relation to weekly physical activity was calculated to be 0.02 with a p-value of 0.50.

The mean PEF, IRV, ERV, and FVC for non-divers who participated in a moderate amount of physical activity weekly were 3.07L/s, 2.00L, 1.77L, and 3.78L respective. The single non-diver who participated in an above average amount of physical activity weekly had a PEF, IRV, ERV, and FVC of 8.64L/s, 1.57L, 2.64L, and 4.22L respectively. Non-divers who participated in little to no weekly activity had a mean PEF, IRV, ERV, and FVC of 2.67L/s, 1.57L, 1.72L/s, and 3.28L respectively. The mean PEF, IRV, ERV, and FVC of divers and non-divers in relation to amount of weekly physical activity is summarized in Figure 6.

Regression analysis was used to analyze the relationship between PEF, IRV, ERV, and FVC and weekly physical activity. Non-diver PEF in relation to weekly physical activity produced a r-squared value of 0.13 with a p-value of 1.86. Non-diver IRV in relation to weekly physical activity produced an r-squared value of <0.01 with a p-value of 0.08, while non-diver ERV in relation to physical weekly activity produced an r-squared value of 0.05 with a p-squared value of 0.26. Non-diver FVC in relation to weekly physical activity produced an r-squared value of 0.03 with a p-value of 0.04. Table 5 summarizes the r-squared and p-values for diver and non-diver PEF, IRV, ERV, and FVC in relation to weekly physical activity.

Divers: Number of Logged Dives

The r-squared value for diver PEF in relation to number of logged dives is 0.02 with a p-value of 0.50. Diver IRV in relation to number of logged dives produced an r-squared value of <0.01 with a p-value of

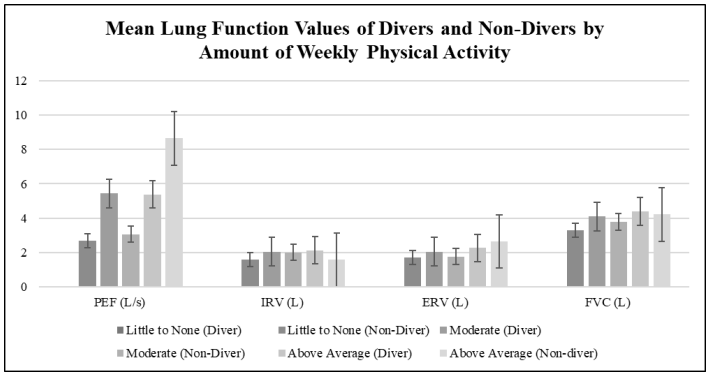

Figure 6. Mean lung function values of divers and non-divers in relation to amount of weekly physical activity.

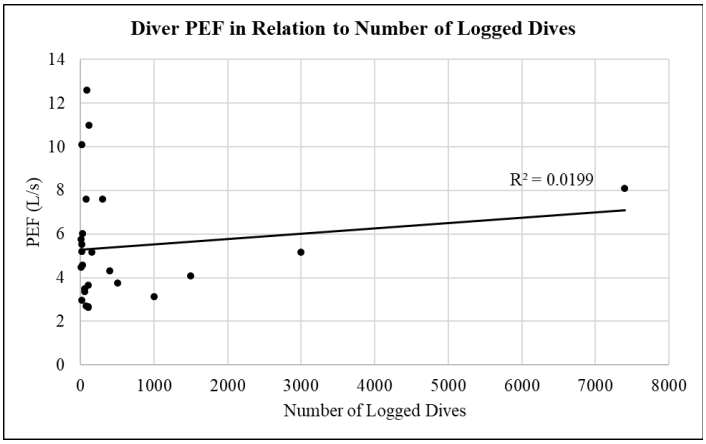

Figure 7. Regression analysis of diver PEF in relation to number of logged dives.

Table 5. R-squared and p-values of lung function values of divers and non-divers in relation to weekly physical activity. A "*" indicates statistical significance.

		Divers	Non-divers
PEF	*R-Squared*	<0.01	0.13
	P-Value	0.94	1.86
IRV	*R-Squared*	<0.01	<0.01
	P-Value	0.76	0.08
ERV	*R-Squared*	0.01	0.05
	P-Value	0.58	0.26
FVC	*R-Squared*	0.02	0.03*
	P-Value	0.50	0.04*

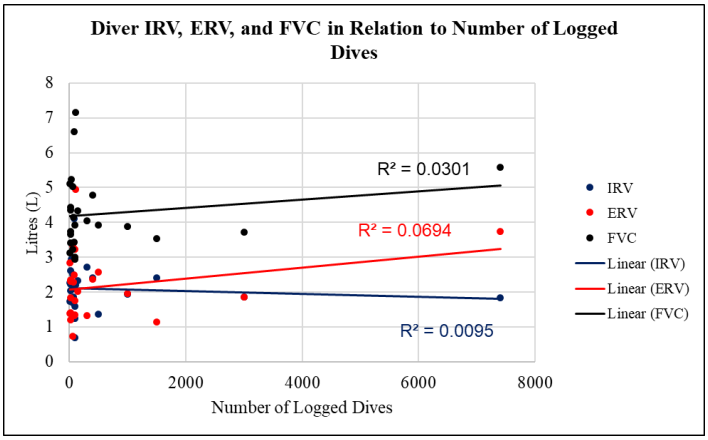

Figure 8. Regression analysis of diver IRV, ERV, and FVC in relation to number of logged dives.

0.06, while diver ERV in relation to number of logged dives produced an r-squared value of 0.07 with a p-value of 0.20. The r-squared value for diver FVC in relation to number of logged dives was calculated to be 0.03 with a p-value of 0.41. Table 6 summarizes the r-squared and p-values for diver PEF, IRV, ERV, and FVC in relation to number of logged dives. Also, the regression analysis for diver PEF is summarized in Figure 7, and the regression analysis for diver IRV, ERV, and FVC is summarized in Figure 8.

Table 6. R-squared and p-values of lung function values of divers in relation to number of logged dives.

PEF	*R-Squared*	0.02
	P-Value	0.50
IRV	*R-Squared*	<0.01
	P-Value	0.06
ERV	*R-Squared*	0.07
	P-Value	0.20
FVC	*R-Squared*	0.03
	P-Value	0.41

Divers: Dive Tenure (Years as a Certified SCUBA Diver)

The r-squared value for diver PEF in relation to dive tenure was calculated to be <0.01 with a p-value of 0.90. Diver IRV in relation to dive tenure produced an r-squared value of 0.07 with a p-value of 0.20, while diver ERV in relation to dive tenure produced an r-square value of 0.08 with a p-value of 0.15. Diver FVC in relation to dive tenure produced a r-squared value of <0.01 with a p-value of 0.65. Table 7 shows the r-squared and p-values for diver PEF, IRV, ERV, and FVC in relation to dive tenure. Figure 9 shows the regression analysis of diver PEF in relation to dive tenure, while Figure 10 shows the regression analysis of diver IRV, ERV, and FVC in relation to dive tenure.

Table 7. R-squared and p-values of lung function values of divers in relation to dive tenure.

PEF	*R-Squared*	<0.01
	P-Value	0.90
IRV	*R-Squared*	0.07
	P-Value	0.20
ERV	*R-Squared*	0.08
	P-Value	0.15
FVC	*R-Squared*	<0.01
	P-Value	0.65

Divers: Certification Level

For Open Water divers, the mean PEF, IRV, ERV, and FVC values were 5.82L/s, 2.00L, 2.54L, and 4.56L respectively. For advanced open water divers, the mean PEF, IRV, ERV, and FVC values were 4.95L/s, 2.24L, 1.79L, and 4.03L respectively. Rescue divers had mean PEF,

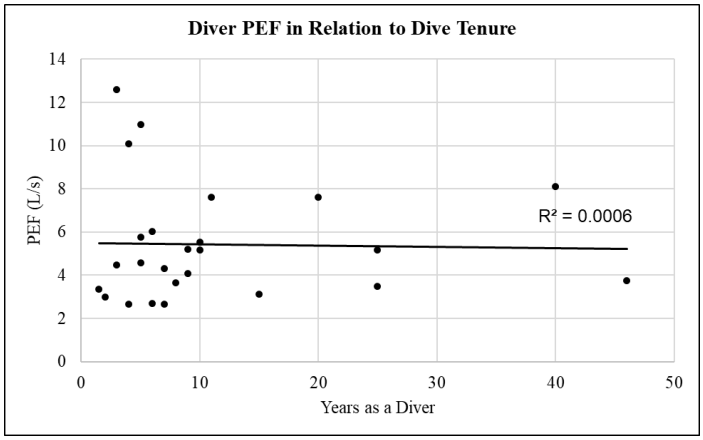

Figure 9. Regression analysis of diver PEF in relation to dive tenure.

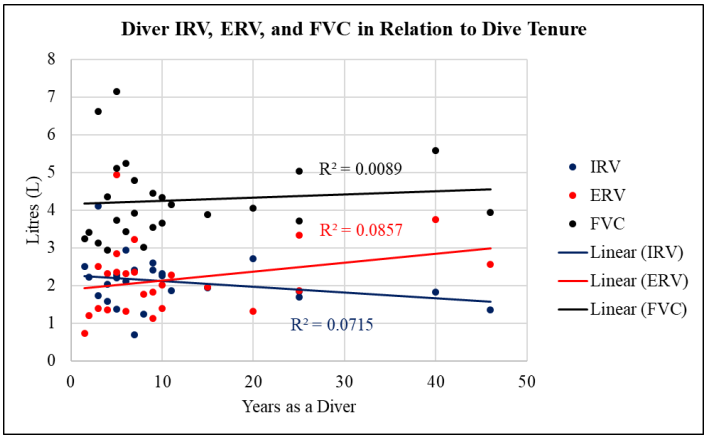

Figure 10. Regression Analysis of diver IRV, ERV, and FVC in relation to dive tenure.

IRV, ERV, and FVC values of 6.78L/s, 2.22L, 2.50L, 4.72L respectively. Professional level divers had a mean PEF, IRV, ERV, and FVC values of 4.97L/s, 1.97L, 2.09L, and 4.07L respectively. Figure 11 summarizes the mean PEF, IRV, ERV, and FVC values of open water, advanced open water, rescue, and professional level divers.

Diver PEF in relation to diver certification level produced a r-squared value of <0.01 with a p-value of 0.77. Diver IRV in relation to diver certification level produced an r-squared value of <0.01 with a p-value of 0.78, while diver ERV in relation to diver certification level produced an r-squared value of <0.01 with a p-value of 0.75. The r-squared value for diver FVC in relation to diver certification level was <0.01 with a p-value of 0.65. Table 8 summarizes the r-squared and p-values of diver PEF, IRV, ERV, and FVC in relation to certification level.

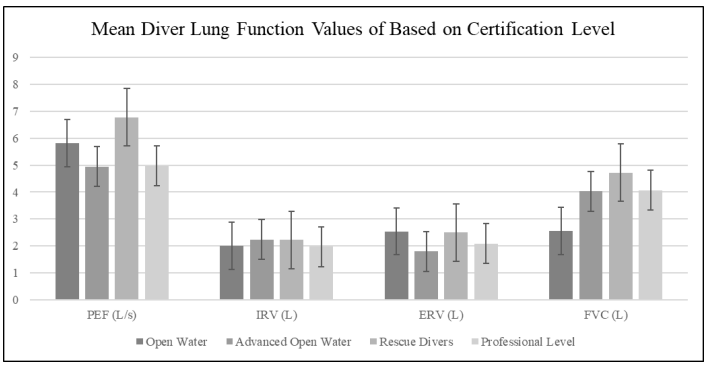

Figure 11. Mean diver PEF, IRV, ERV, and FVC values in relation to certification levels.

Table 8. R-squared and p-values of lung function values of divers in relation to certification level.

PEF	*R-Squared*	<0.01
	P-Value	0.77
IRV	*R-Squared*	<0.01
	P-Value	0.78
ERV	*R-Squared*	<0.01
	P-Value	0.75
FVC	*R-Squared*	<0.01
	P-Value	0.65

Divers: Gas Mix

The mean PEF, IRV, ERV, and FVC of divers who primarily used standard air were 5.48L/s, 1.87L, 2.46L, and 4.33L respectively. The mean PEF, IRV, ERV, and FVC of divers who primarily dove on NITROX were 5.36L/s, 1.87L, 2.45L, and 4.33L respectively. Figure 12 summarizes the mean diver PEF, IRV, ERV, and FVC in relation to gas mixture.

Diver PEF in relation to gas mix produced a r-squared value of <0.1 with a p-value of 0.89. Diver IRV in relation to gas mix produced a r-squared value of 0.07 with a p-value of 0.20, while diver ERV in relation to gas mix produced an r-squared value of 0.02 with a p-value of 0.45. The r-squared value of diver FVC in relation to gas mix was calculated to be <0.01 with a p-value of 0.90.

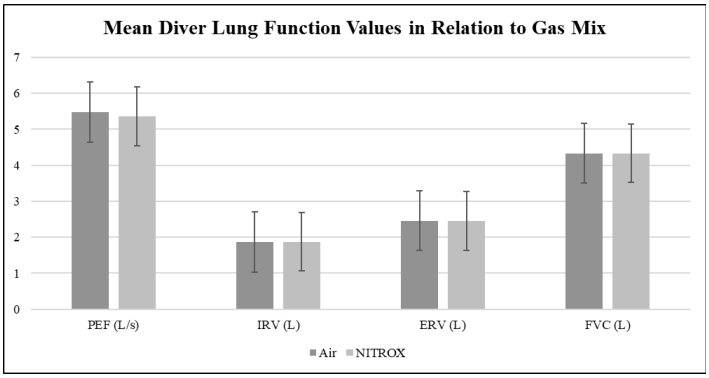

Figure 12. Mean diver PEF, IRV, ERV, and FVC in relation to gas mixture.

Table 9. R-squared and p-values of lung function values of divers in relation to gas mixture.

PEF	*R-Squared*	<0.1
	P-Value	0.89
IRV	*R-Squared*	0.07
	P-Value	0.20
ERV	*R-Squared*	0.02
	P-Value	0.45
FVC	*R-Squared*	<0.01
	P-Value	0.90

Discussion

Given the results for sex between divers and non-divers, the data suggest that there is a statistically significant difference between the two groups' FVC in relation to sex with 18% of future cases being explained. Diver ERV in relation to sex also produced statistically significant results with 24% of future cases being explained according to this study. While both male and female diver participants had a mean ERV of 1.50L/s, it is important to note that a mean value can be obtained with a variety of values. The results of this study suggest that 24% of the variation in ERV of the values used to calculate the mean is related to sex. Neither diver or non-diver IRV or PEF, as well as non-diver ERV, produced statistically significant results in relation to sex.

This study also suggests that there is a statistically significant correlation between diver ERV and age, with 24% of future cases being explained. The figure also suggests that there is a positive correlation between diver FVC and age, and a negative correlation between diver IRV and age; however, there is no statistical significance with either variable in this study. Figure 6 infers that there is a positive correlation between non-diver IRV and FVC and age, and a negative correlation between non-diver ERV and age. However, again, there is no statistical significance with these findings.

Non-diver FVC in relation to weekly physical activity produced a statistically significant result as well with 3% of FVC variation being explained by weekly physical activity. There were no statistically significant results between any of the four dependent variables and divers in relation to weekly physical activity. Non-diver PEF, ERV, and IRV did not show any statistically significant relationships to physical activity. The lack of statistical significance in this portion of the study could be caused by the subjective nature of the physical activity question on the survey. Those completing the survey were often preoccupied with getting on the dive vessel and not too concerned with the study. Many respondents could have also given way to the response bias, which states that those completing a survey often portray themselves in the best light[8]. The central tendency bias, which is the phenomena where participants avoid answering extremes, could have also played a role in the survey responses[7]. This is seen in the non-diver population, as only two of the twenty-five participants claimed that they participated in less than average physical activity, with the others selecting a "moderate" amount of physical weekly activity.

In relation to number of logged dives, there once again seems to be a positive correlation between diver PEF, ERV, and FVC, and a negative correlation between diver IRV. However, none of these results are statistically significant. Dive tenure produced similar statistically insignificant results, except that diver PEF in relation to dive tenure seemed to have a slight negative correlation. In some cases, divers stopped logging their dives, which could have led to estimation errors on the survey.

Certification level in relation to diver lung function values also produced statistically insignificant results. While a study by Skogstad and colleagues did not show a significant change in FVC of divers from the beginning to end of their professional course[9], PADI's standards are worded so that one has the opportunity to earn recreational certifications in rapid succession. For example, a newly certified Open Water diver with four open water dives can immediately go on to earn an Advanced Open Water Certification after competing five additional open water dives. However, one with an open water certification may not go on to earn an Advanced Open Water certification but may log hundreds of dives. Though the first diver has a higher-ranking certification, the second diver has more experience and exposure to the physiological changes that occur while diving.

Gas mix in relation to diver lung function values also produced statistically insignificant results. A study by Zenske and colleagues suggests that enriched air nitrox may lead to oxidative stress on smaller pulmonary airways. However, in this study, it was unknown if divers were diving consistently with the air mixture chosen on the survey, as the survey asked what the participants dove with more frequently[12].

It is also important to note that both populations in this study were rather small. A larger sample size may have affected the statistical significance of the variables under study. Aside from sample size, while some results showed statistical significance, further investigation is needed to understand the clinical significance of these results. In a clinical review Coop and colleagues discussed that patients presenting with asthma have increased risks associated with diving; however, asthmatics, generally speaking, are not forbidden from the recreational sport[1]. PADI also requires divers to complete a medical statement to evaluate whether an individual is medically cleared to dive. However, further research is needed to understand diving as a respiratory therapy.

It should also be noted that the spirometer used in this experiment, the Logger Pro Mini, is not a clinical grade spirometer. Any possible clinical findings in this study should be replicated with clinical grade equipment. Clinical grade equipment was not available for this study due to financial restraints.

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Notes and References

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